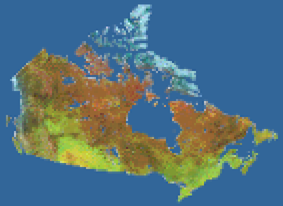

Hyperspectral Remote Sensing for Geological Mapping and Mineral Exploration –A Review of Activities at NRCAN

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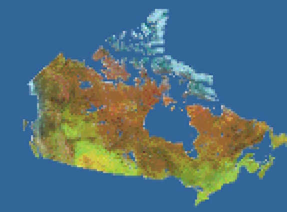
1. Geological Survey of Canada
2. McMaster University
3. Canada Centre for Remote Sensing

Background papers….

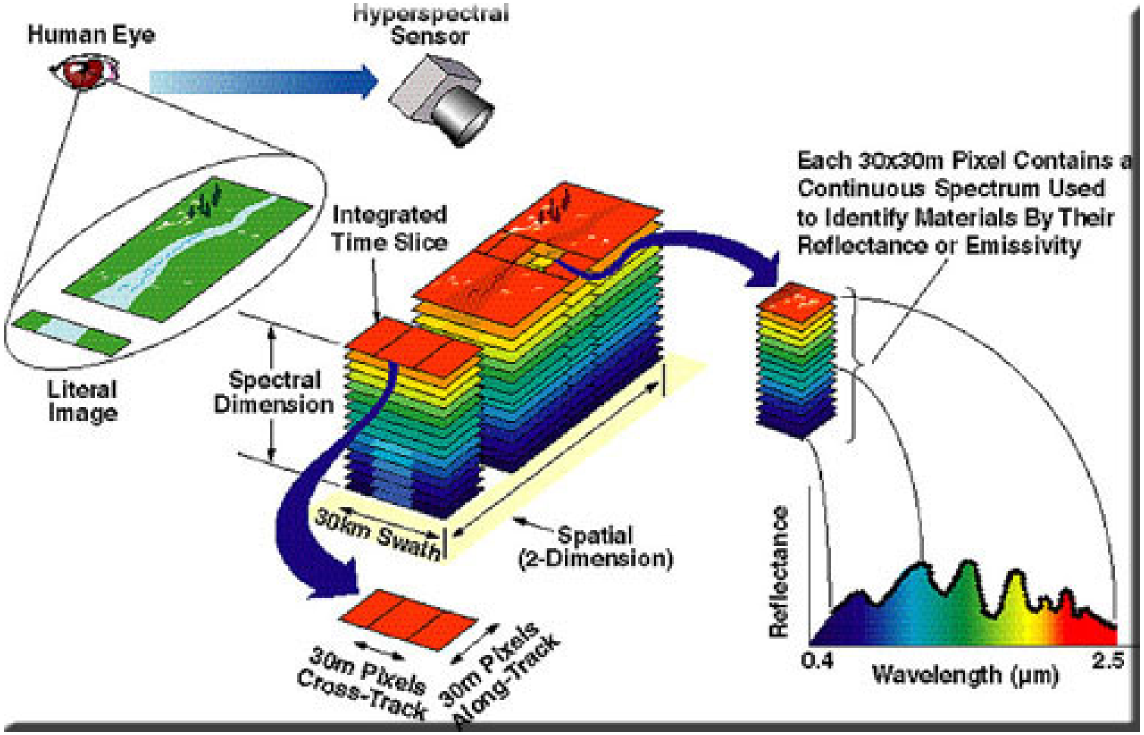
- Harris et al. 2005, CJES, V. 42, pp.2173-2193
- Rogge et al. 2007, RSE, Vol 10, Issue 3, pp. 287-303
- Harris et al. 2006, CJRS Vol. 32, no. 5, pp 341-354
- Rogge et al. 2009, Reviews in Economic Geology: Remote Sensing and Spectral Geology, eds., Bedell, R., Crosta, A.P. and Grunsky E., V. 16, Society of Economic Geologists, pp 209-222
- Harris et al. 2010, CJRS, Vol. 36, No. 4

The Hyperspectral World



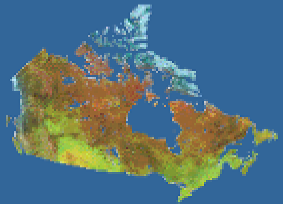
- The acquisition of images in hundreds of registered, contiguous spectral bands such that for each picture element (pixel) of an image it is possible to derive a complete reflectance spectrum" (Goetz et al., 1985)
- Many bands – narrow band width – 10 – 15 nanometers – high spectral resolution – **moving from the world of discrimination to identification!**
- Generally high spatial resolution (at least on airborne platforms)
- All systems are airborne except for one –*Hyperion* but many are coming!
- More complicated processing!
  - DN-radiance
  - Atmospheric

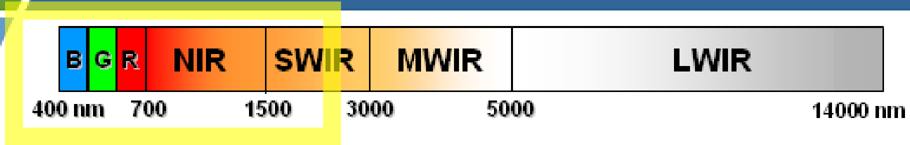
Hyperspectral Imaging



- Layers or bands are select slices of the light spectrum, each of which contains different information about surface composition
- **Each pixel stack is a spectra that provides information about the surface composition"fingerprint"**

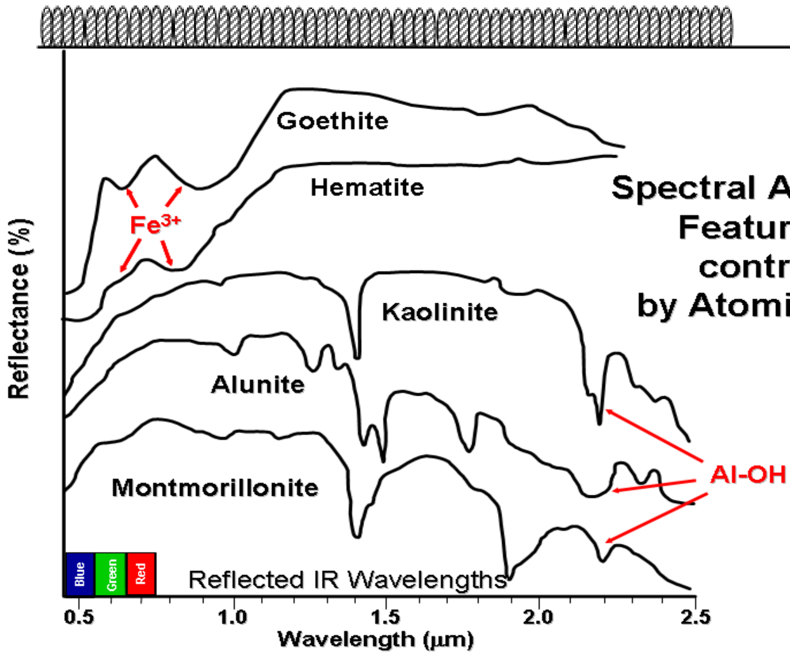
Multispectral Versus Hyperspectral Spectral Resolution!



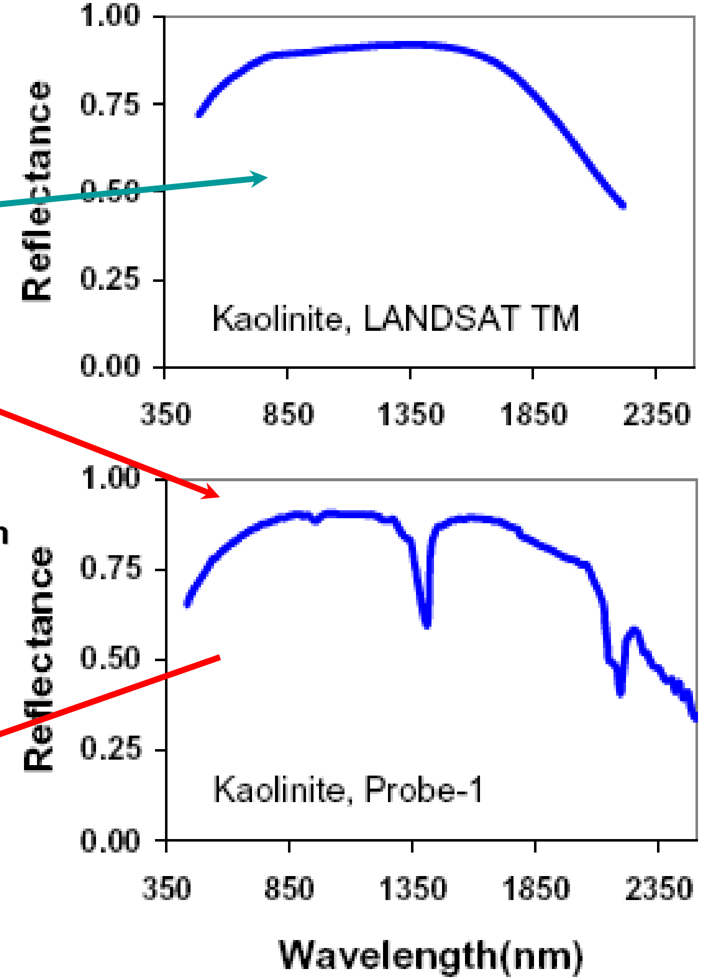


Multispectral: several to tens of bands

Hyperspectral: hundreds of narrow bands



Spectral Absorption Features are controlled by Atomic Bonds



Unique Spectra

- Controls on absorption →
  - **electronic transitions and charge transfer processes** (changes in energy states of electrons bound to to atoms or molecules) associated with transition elements - **Fe**, Cr, Ti etc. - determine the position of diagnostic absorption bands in the VNIR
  - **Vibrational processes** (small displacements of atoms around their resting positions) in **H_2O** and **OH^-** and **CO_3** results in fundamental overtone absorptions in the SWIR
  - Higher energy levels required required for electronic processes, therefore occur at shorter wavelengths → result in broad absorption features (i.e. Fe) – SWIR – sharper and deeper absorption features (less energy required)

  - Manifestations of these effects:

What are the characteristics of a spectra that we look for?

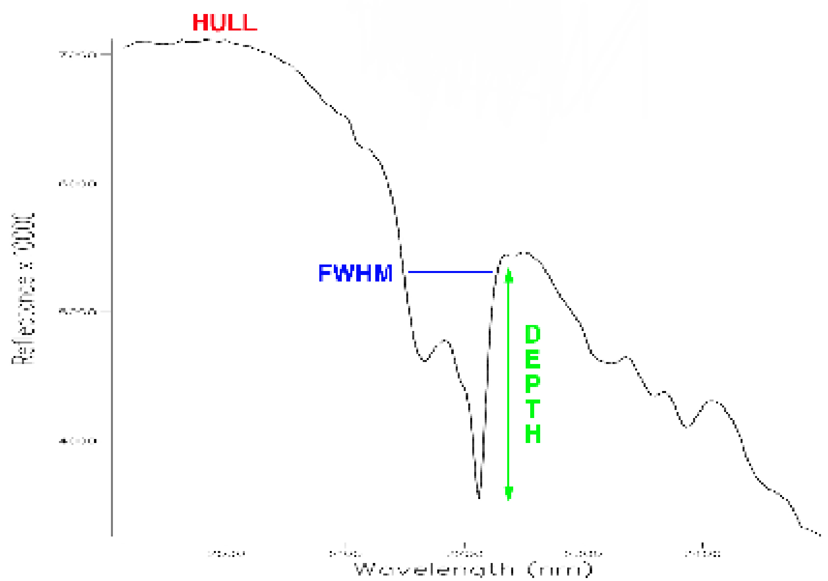
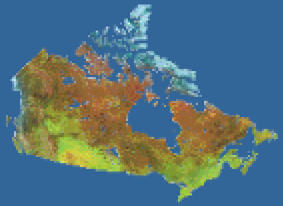


Figure 1 – The components of a reflectance spectrum include the hull or continuum, the absorption minima or feature, the band position of the minima as a wavelength value, the Full Width Half Maxima of the absorption feature, the depth of the feature, as reflectance.

….Spectral Variability will result in the shift in position and shape of absorption bands as well as suppress spectra

- Chemical variability (calcite → dolomite and solid solution series)
- Grain size (smaller grain size = higher reflectance)
- Illumination conditions / topography – very import for Northern environments
- Atmosphere (lab measurements vs. in situ or airborne measurements)
- Weathering – hyperspectral sensors only see what is on the surface – no penetration!

Alteration Minerals Identifiable by Short Wave Infrared Spectrometry



- **Clays:** Kaolinite, Dickite, Halloysite, Pyrophyllite, Illite-Smectite, Montmorillionite
- **Micas:** White mica (Sericite), Illite, Phengite, Muscovite, Paragonite, Biotite, Phlogopite, Pyrophyllite, etc.
- **Chlorites:** Variations in Fe, Mg content
- **Other Phyllosilicates:** Serpentines (Lizardite, Antigorite), Fuchsite, Talc, Nontronite
- **Amphiboles:** Tremolite, Hornblende, Actinolite, Anthophyllite
- **Carbonates:** Calcite, Dolomite, Ankerite, Siderite
- **Sulphates:** Alunite, Jarosite, Gypsum
- **Tourmaline:** Fe-tourmaline, Tourmaline

  - **Major Absorptions:**
    - **Al-OH:** clays, micas
    - **Fe-OH:** chlorites, serpentines
    - **Mg-OH:** serpentines, chlorites, micas, epidote, some amphiboles

BUT !……rocks are composed of a combination of minerals, therefore it cannot be expected that the spectral features of rocks will be as well defined as the spectral features of individual minerals – the difference in application between geological mapping and mineral exploration (detecting suites of alteration minerals)

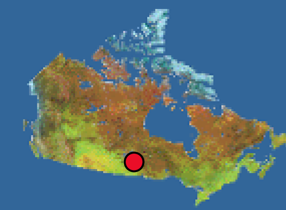
What about the Canadian Environment?

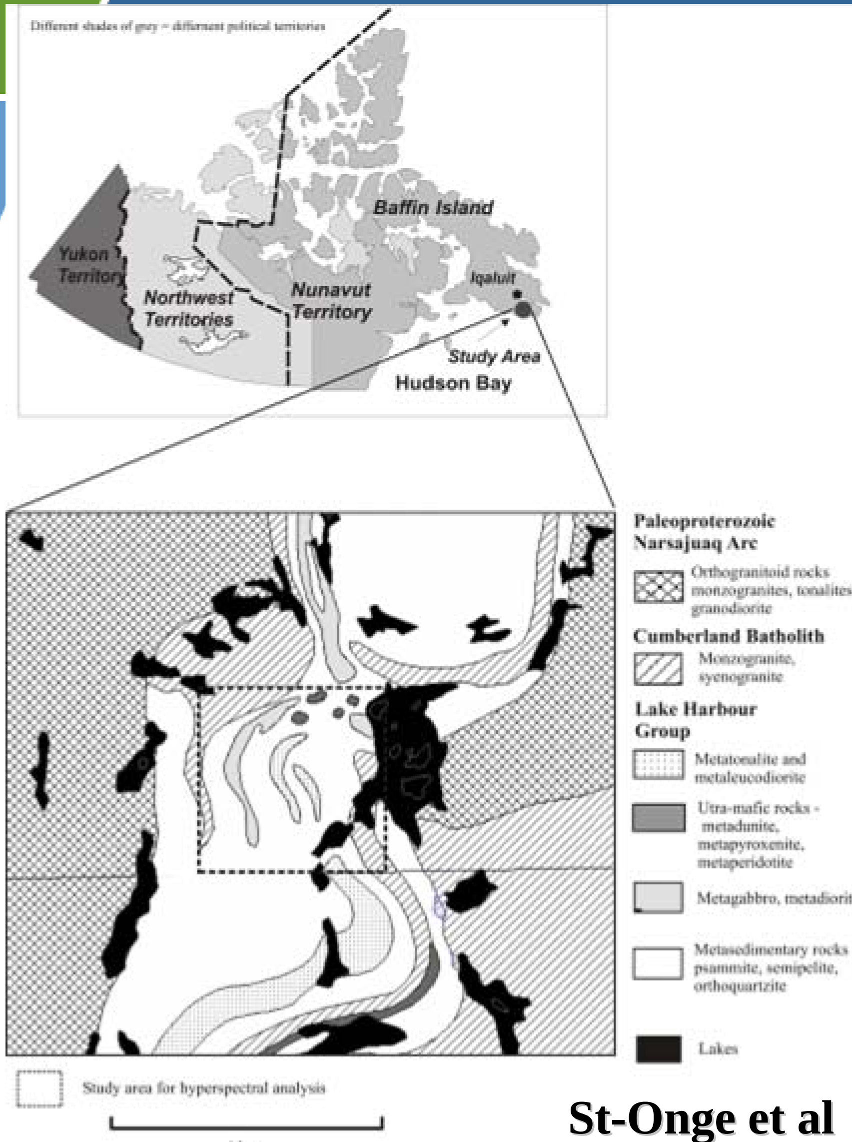
Northern vs. southern environments

Vegetation (south) and lichen (north)!!!!

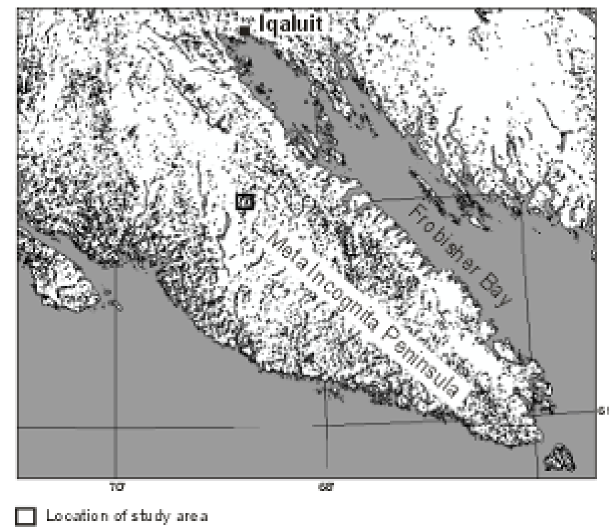
Geological Mapping (bedrock)

Example # 1 – Southeast Baffin Island



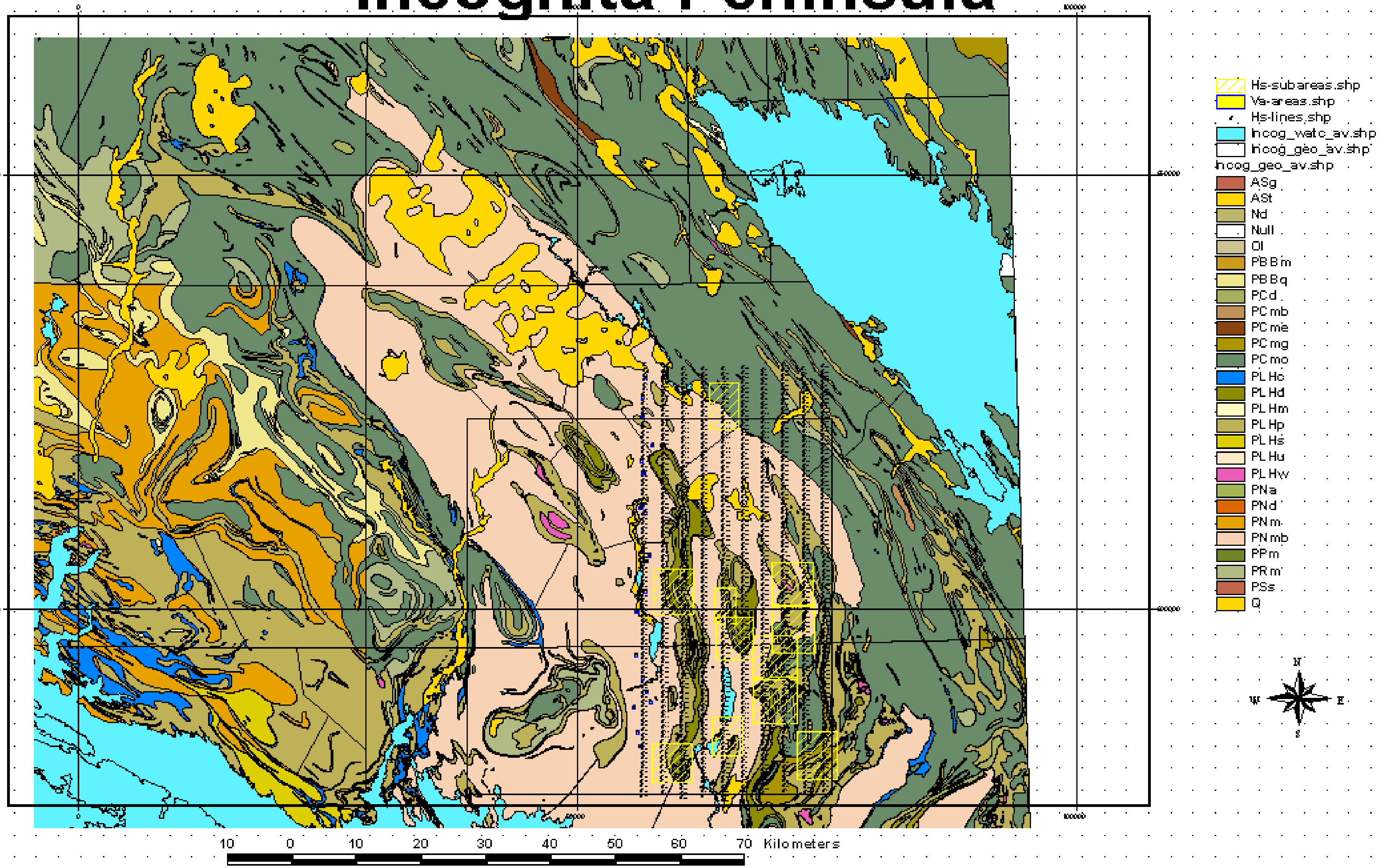


St-Onge et al

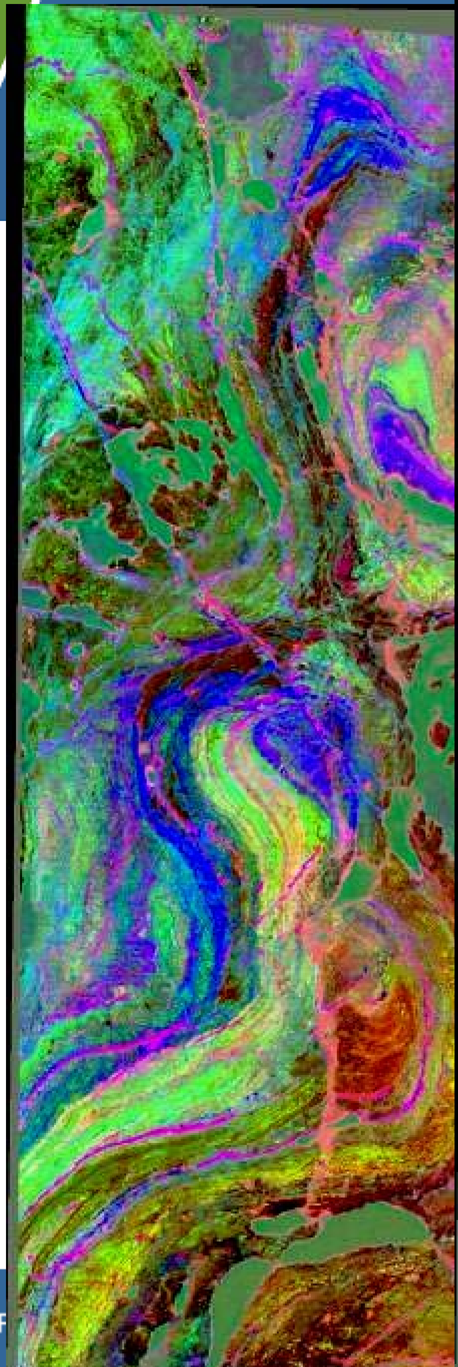


Source – J.R. Harris et al – CJES

Incognita Peninsula



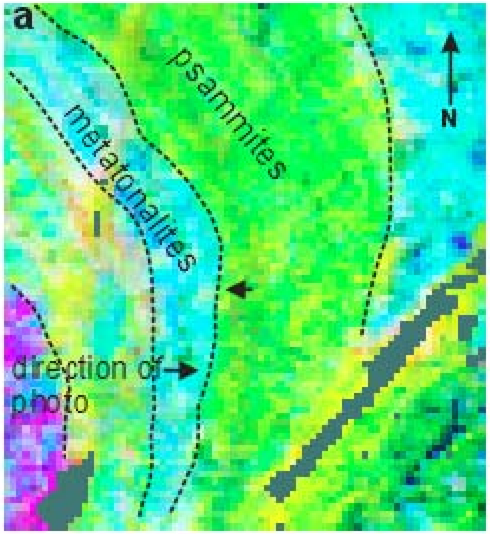
MNF Ternary Image



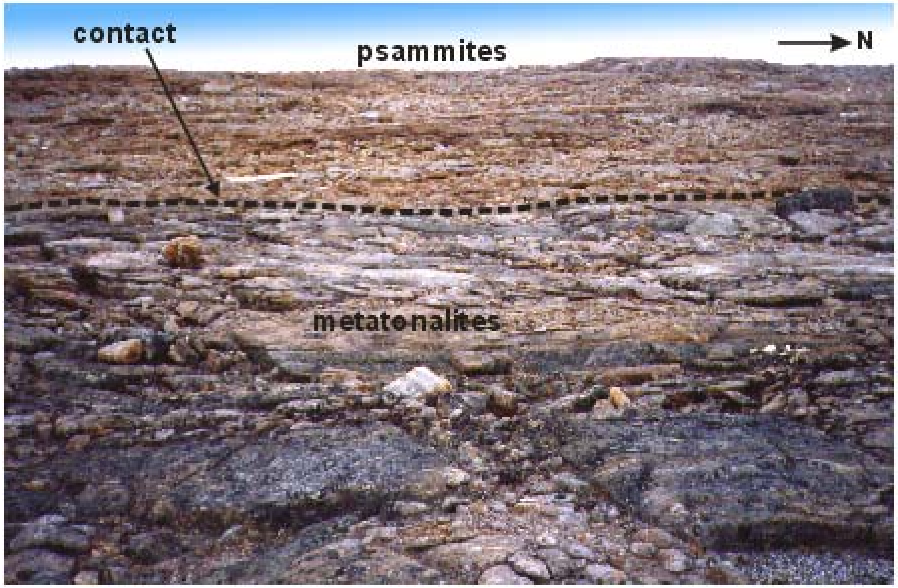
Wow!…..great colours but do they represent lithology??

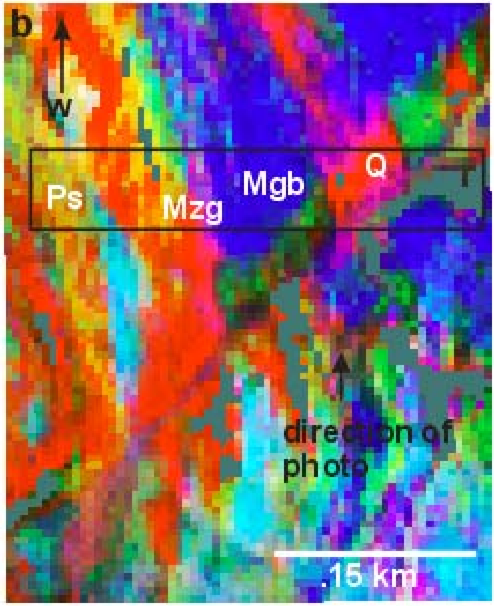
…….results of field work

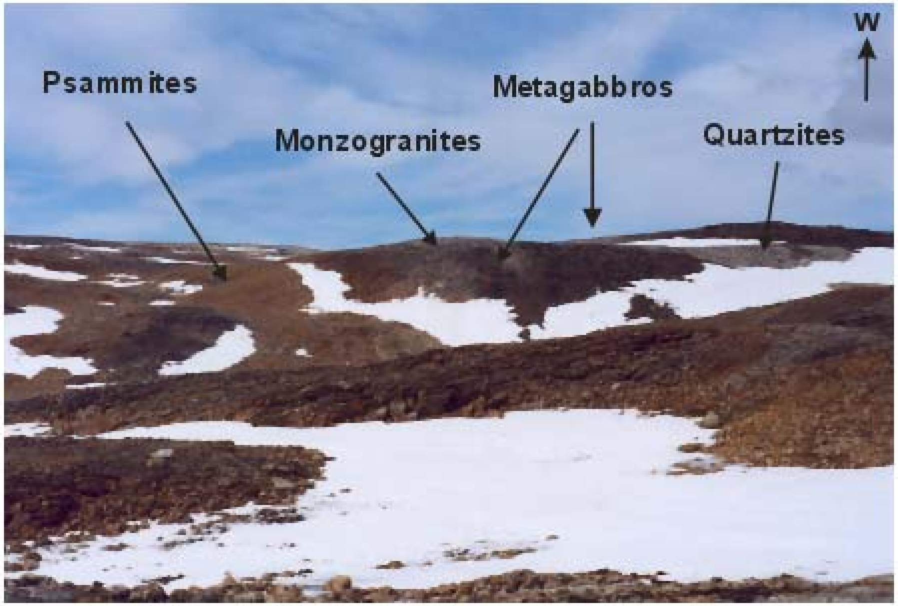
Rock Type	MNF colour	Weathering colour	Primary minerals	Secondary minerals
Ortho-quartzite	Red	white	Qtz	
Metasedimen ts	Green – yellow	orange	Plag – 8-15%, Kfeld – 15-30% Qtz – 30-60	Gt – 8 –10%
Metagabbro	Blue (veg!)	dark		
Metatonalites	Cyan	grey	Plag – 25-30% Kfeld – 15-30% Qtz – 30-35	Gt – 5 –10%
Monzogranit es	Magenta	grey	Plag – 20% Kfeld – 40-50% Qtz – 40-50	Gt –3 %

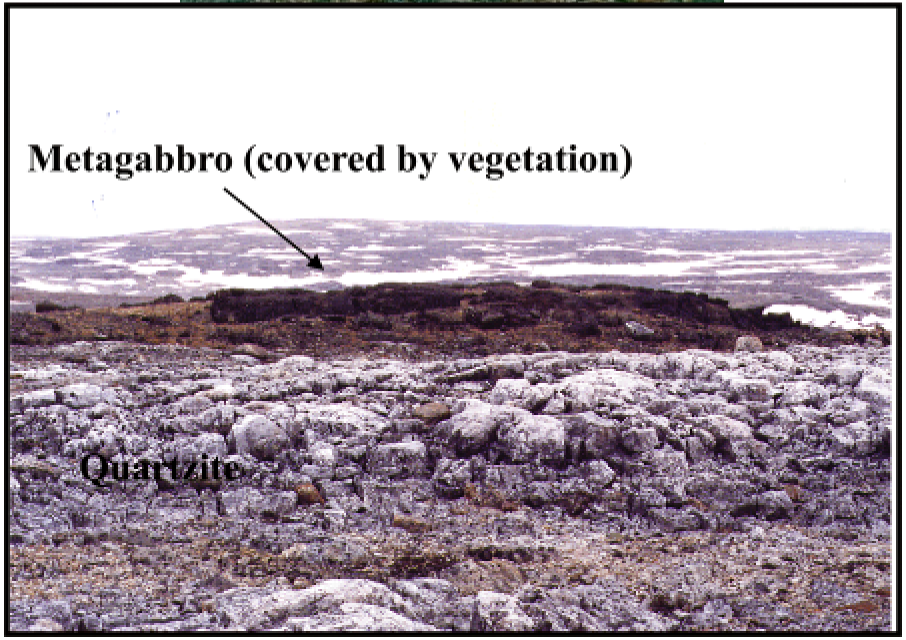

a
psammites
metatonalites
N
direction of photo

--------- contact

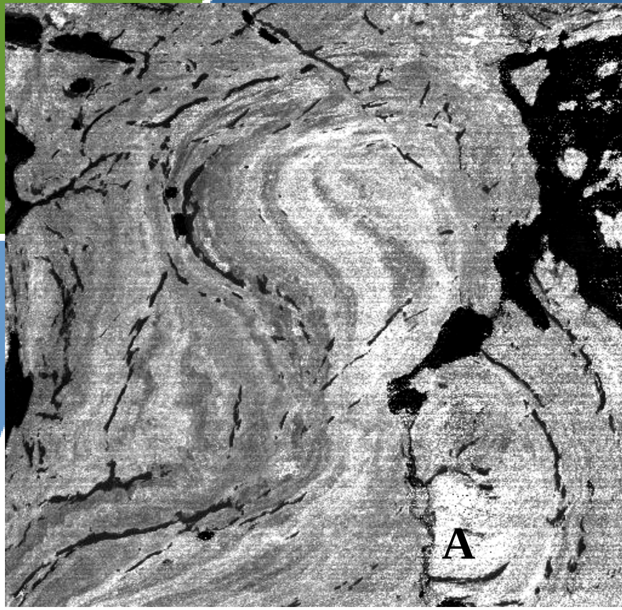

contact
psammites
N
metatonalites


b
W
Ps
Mzg
Mgb
Q
direction of photo
.15 km


W
Psammites
Metagabbros
Monzogranites
Quartzites

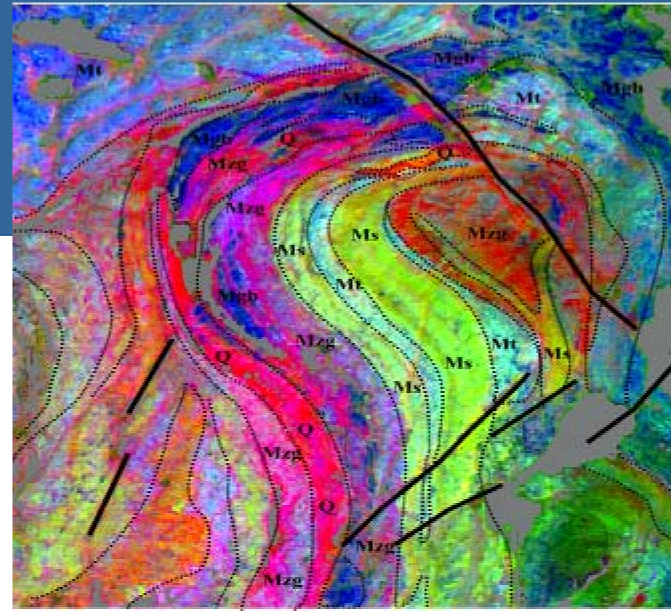


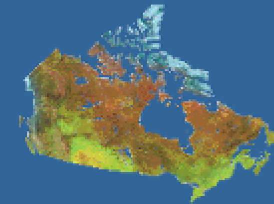
**Metagabbro / diorite –
response to vegetation!**



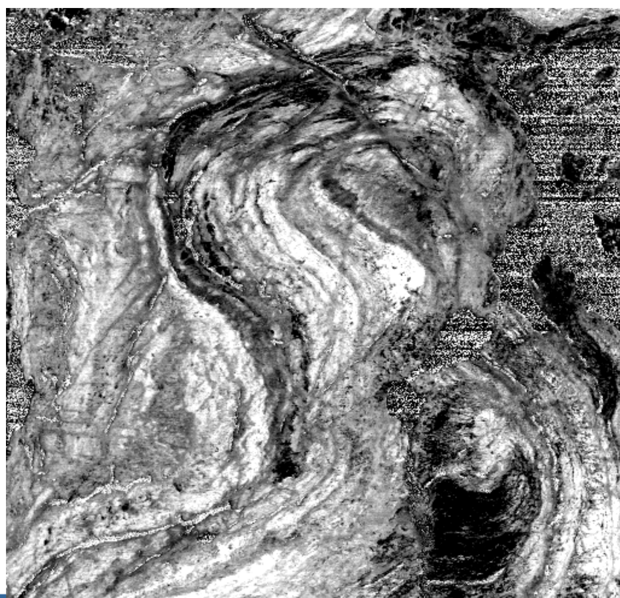
A- Fe ratio (23/1)

Iron ratio image



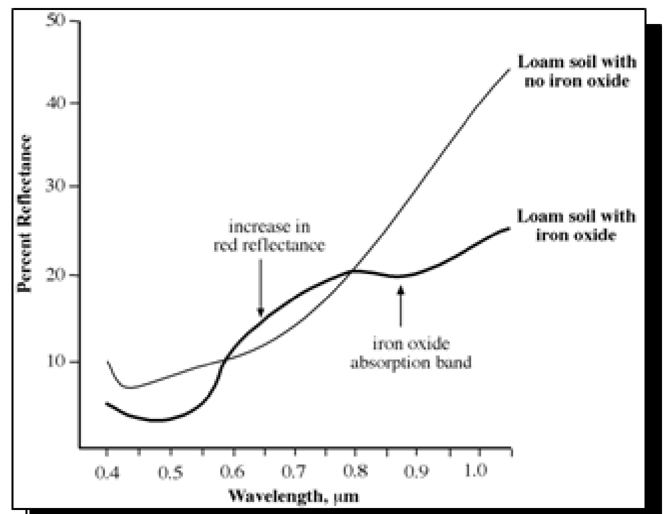


…the importance of iron!

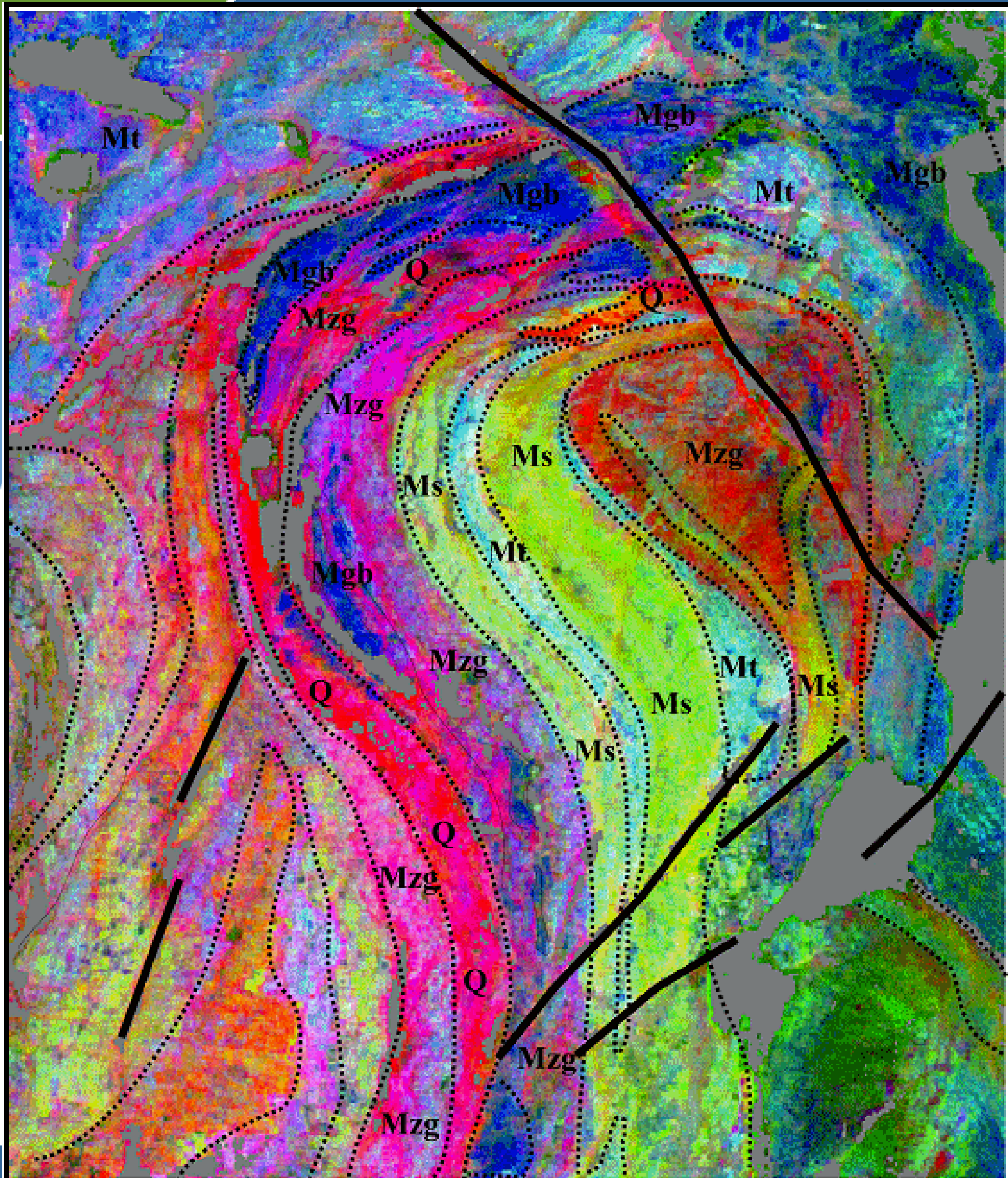


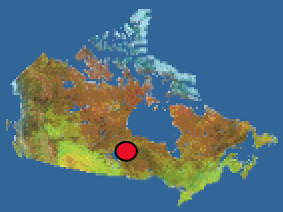
B. Clay ratio (110/77)

Clay ratio image



…making a spectral map



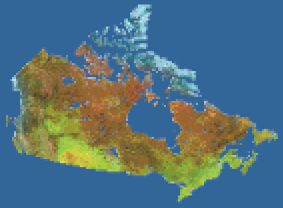


A spectral map can be created by photogeologic interpretation of the MNF image…this is a simple but effective (this is how geologists traditionally create a geology map from air photos!)

1 km

Mineral Exploration

SINED Hyperspectral Project



Project Objective

- To map the hyperspectral response of areas known to host volcanogenic massive sulfide (VMS), Fe-hosted gold and orogenic gold mineralization in Canada's North using airborne hyperspectral sensors.

Project Aim

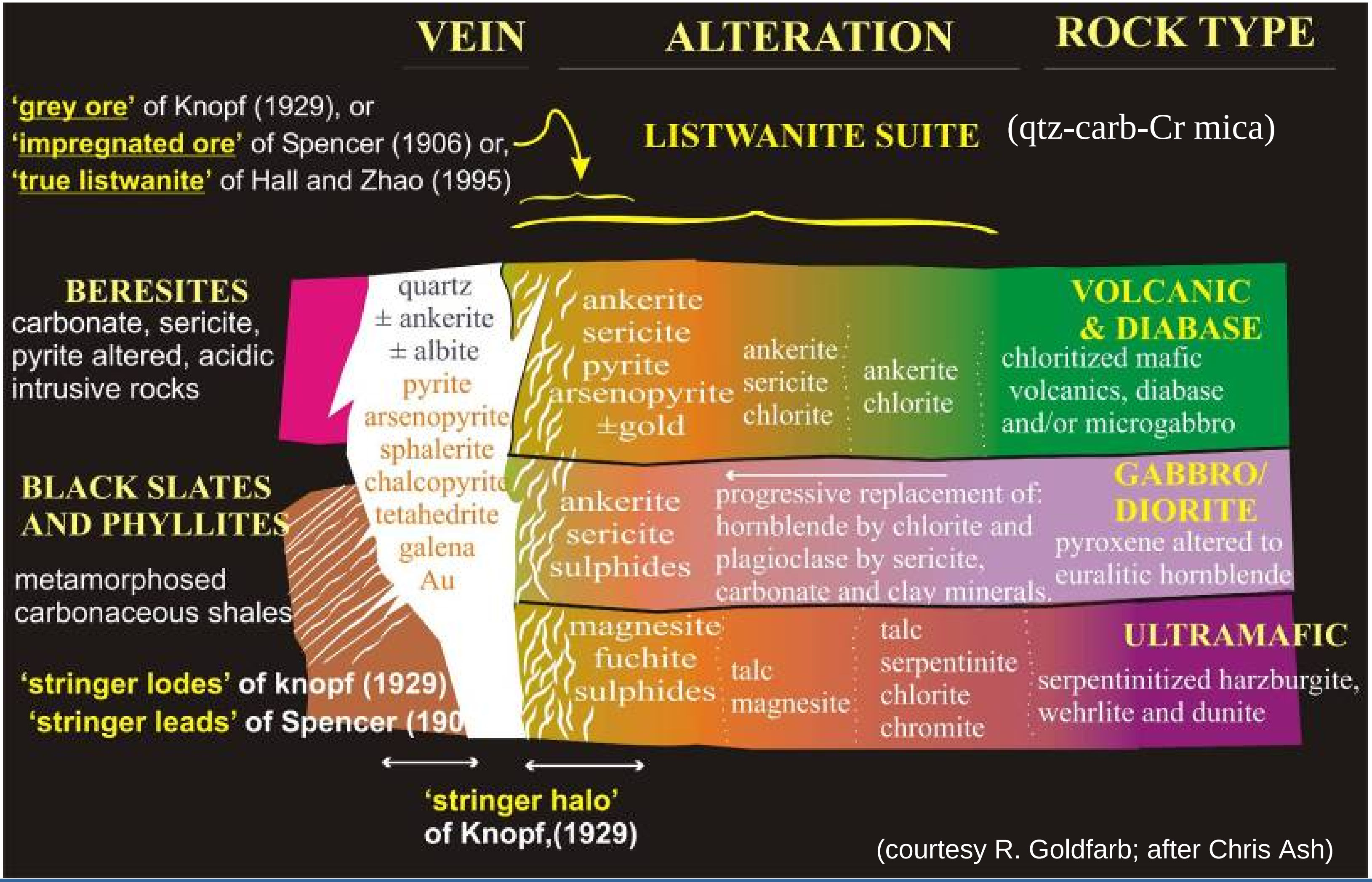
To evaluate the effectiveness of the technology and provide the data:

- To develop methodologies using hyperspectral sensors that can be used to vector toward concealed mineral deposits in Canada’s north (north of 60°) which can be mined, and which will provide employment and revenue for the peoples of Canada’s North; and
- To prepare for the geologic application of hyperspectral satellites that are expected to become available over the next 5 to 10 years and which will significantly assist in the geological mapping (and exploration of) Canada’s North.

Part of larger ESS Project:

- ESS Initiatives to address problems of declining metal reserves in Canada: Deep Search Project (TGI3)

Hydrothermal Alteration Mapping: Orogenic Gold Quartz-Carbonate Veins

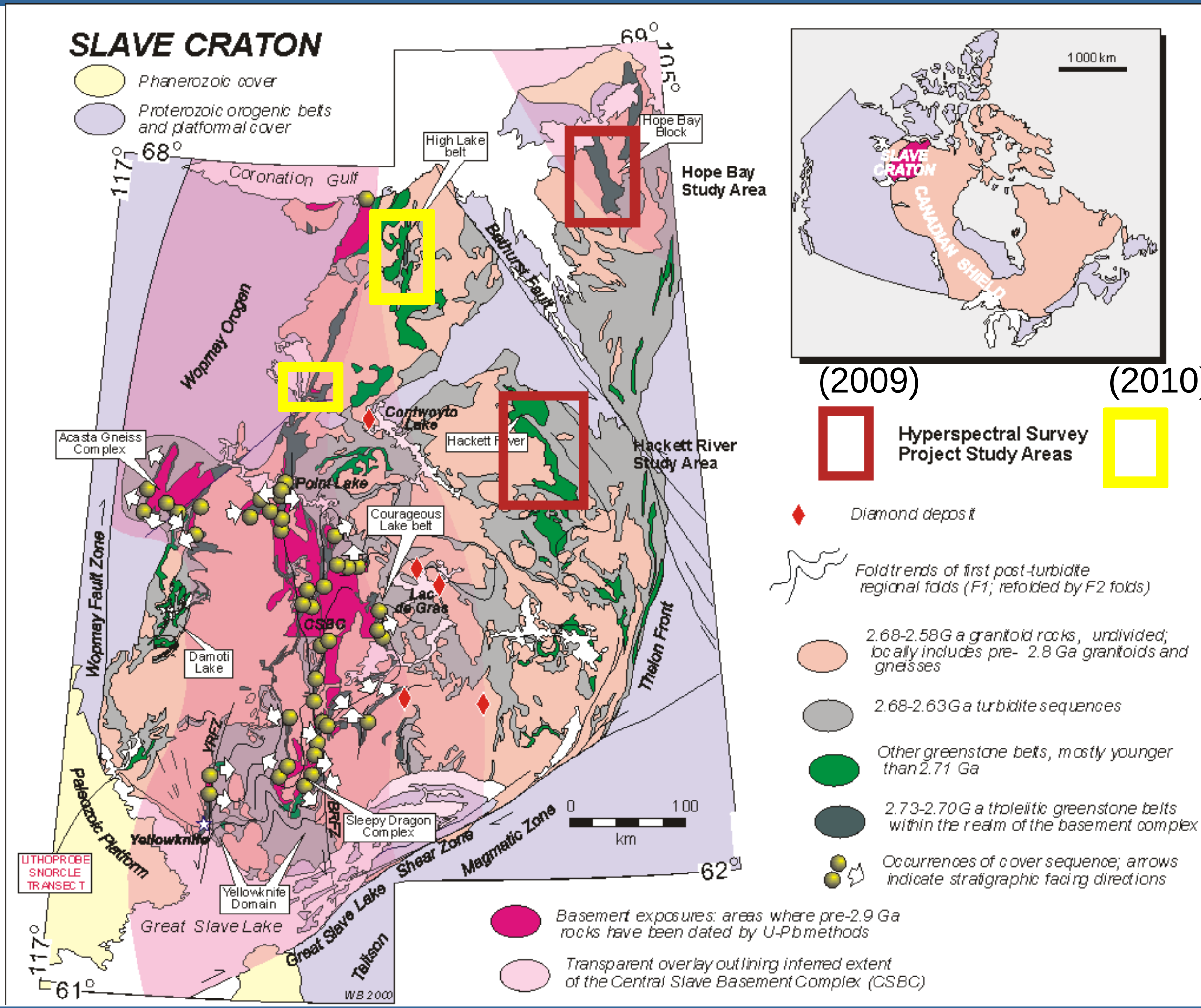


(courtesy R. Goldfarb; after Chris Ash)

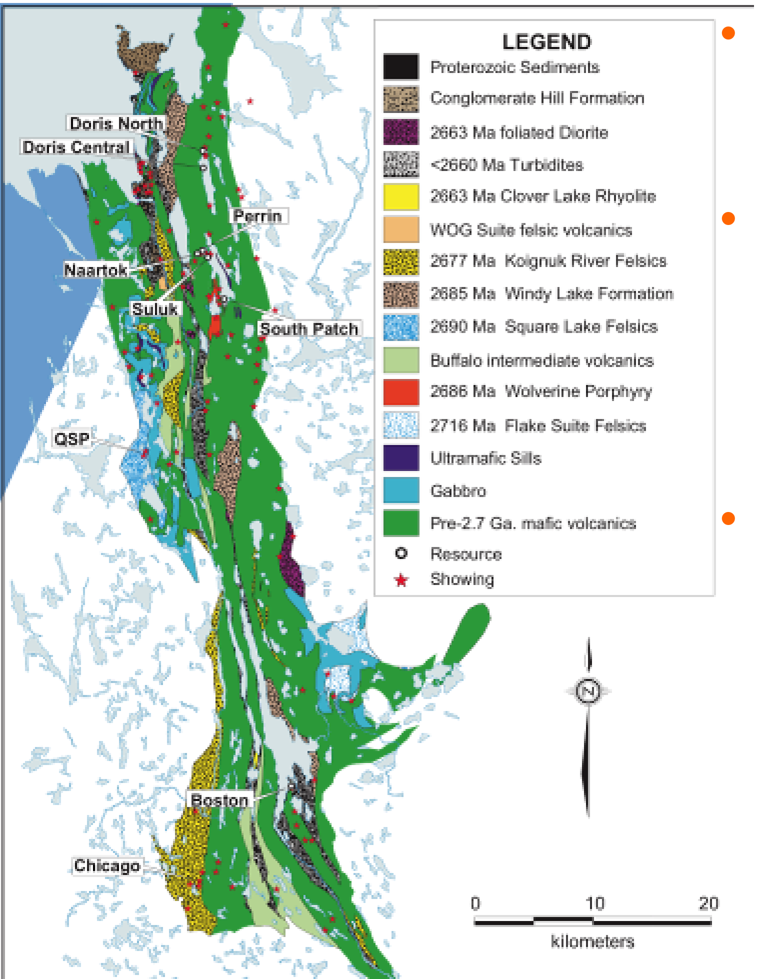
Airborne Hyperspectral Survey Datasets

- Surveys funded by SINED Program (Strategic Investment in Northern Economic Development; originally administered by INAC, and now by Canadian Northern Economic Development Agency)
- 2009: Hackett River Belt, Hope Bay Belt
- 2010: Izok Lake area, High Lake Belt

(Bleeker & Hall, 2007)



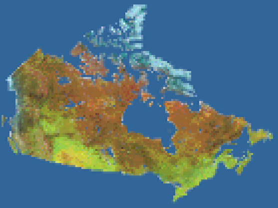
Hope Bay Greenstone Belt



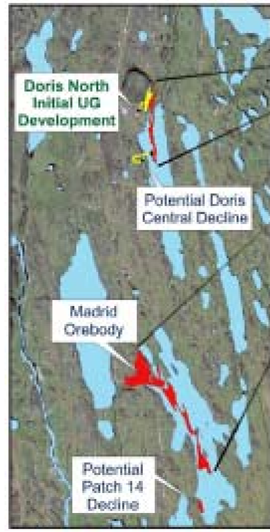
(Therriault, 2006; modified from Miramar Mining)

- ≈90 km long by 15-20 km wide north-trending greenstone belt within the northern part of the Bathurst block, Slave structural province
- **GEOLOGY:** ca. 2700 Ma: primarily mafic volcanics (pillowed tholeiitic basalt, basaltic andesite, and Fe and Mg-rich tholeiite), with intercalated intermediate to felsic volcanic and sedimentary rocks
- **MINERAL DEPOSITS:** shear-zone hosted vein-type orogenic Au deposits, with reported other base metal potential (VMS & some magmatic deposits)
  - Exploration to date has identified a number of potentially economic orogenic Au deposits
    - Doris / Doris N Deposits – Block A (central)
    - Madrid (Naartok, Rand, Suluk) / South Patch – Block A (S)
    - Boston Deposit – Block C (central)

Airborne Hyperspectral Survey: Hope Bay Belt

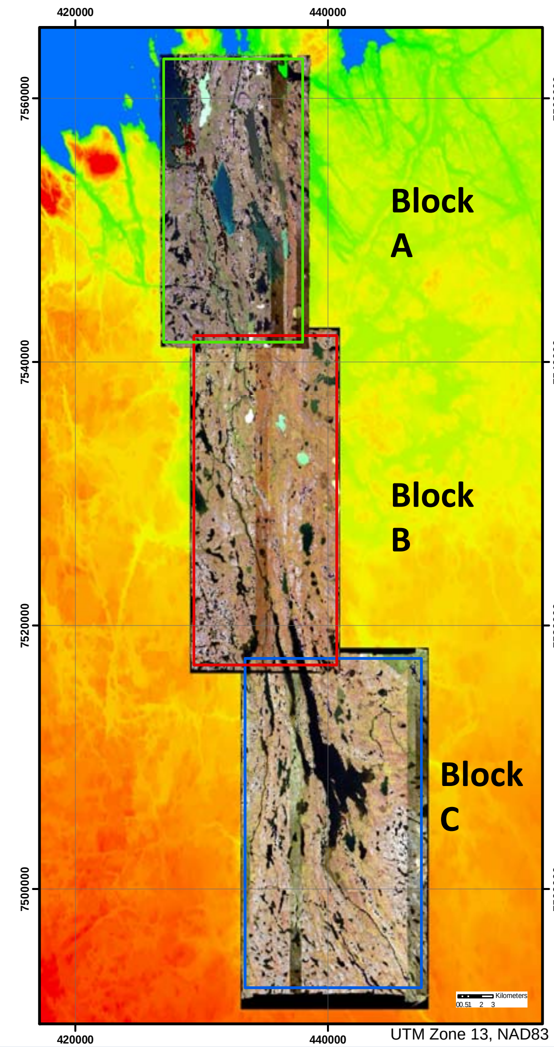


- 3 Blocks: 869 km^2
- Acquisition dates: Aug 21-29, 2009
- Sensor: ProSpecTIR-VS (VNIR-SWIR)
- # bands: 357
- Spectral Range: 400-2450 nm
- Spatial Resolution (GSD): 3m
- Spectral Resolution: 5 nm
- Minimum sun angle: 30 ° (July-August time window)
- Flightline sidelap: min. 30 %
- # Flightlines: 59
- Max. flightline length ~20 km
- Sunny, cloud-free weather



NOTE: all interpretations shown are based on publicly available information (e.g., sedar.com, NRCan publications)

No ground NRCan truthing has been done to date



Hope Bay Hyperspectral Mineral Mapping – Block C (Boston Deposit)

Area: Hope Bay, Block C
Known Mineral Deposit:
Boston – Orogenic Au

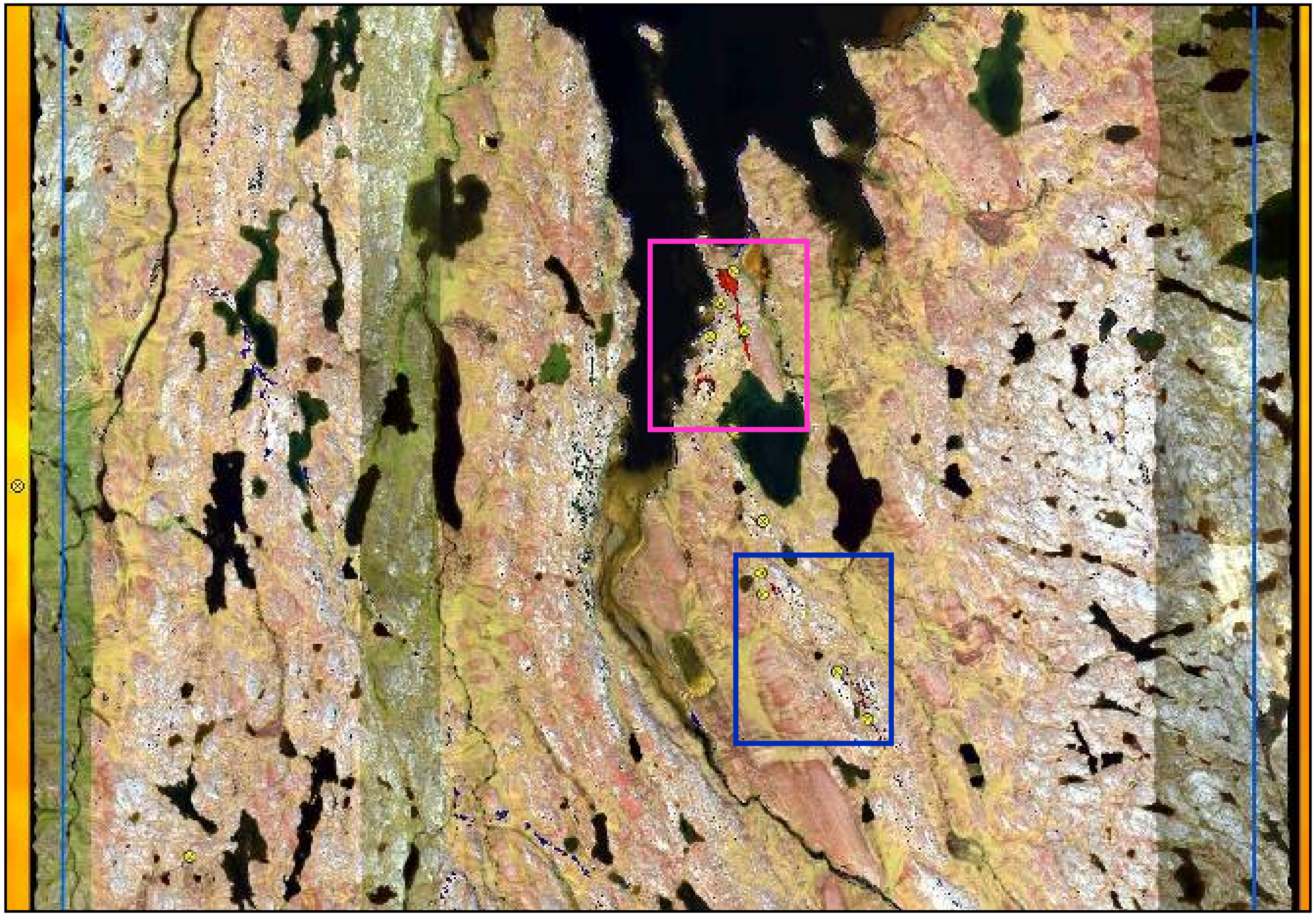
- Image shows reported Au showings, as well as mapped alteration mineralization from SINED survey data

Legend:
SINED mineral Potential results

- Illite - Low Al
- Illite Medium Al
- Illite High Al
- Pyrophyllite
- Chlorite
- NUMIN (GSC) Au occurrences

Areas shown in higher detail in subsequent slides

- Boston (N) Deposit
- Boston (S) Showings



Hope Bay Hyperspectral Mineral Mapping – Block C (Boston Deposit)

Boston Deposit – Alteration Zone + Cultural Features

Boston Area Geology Legend

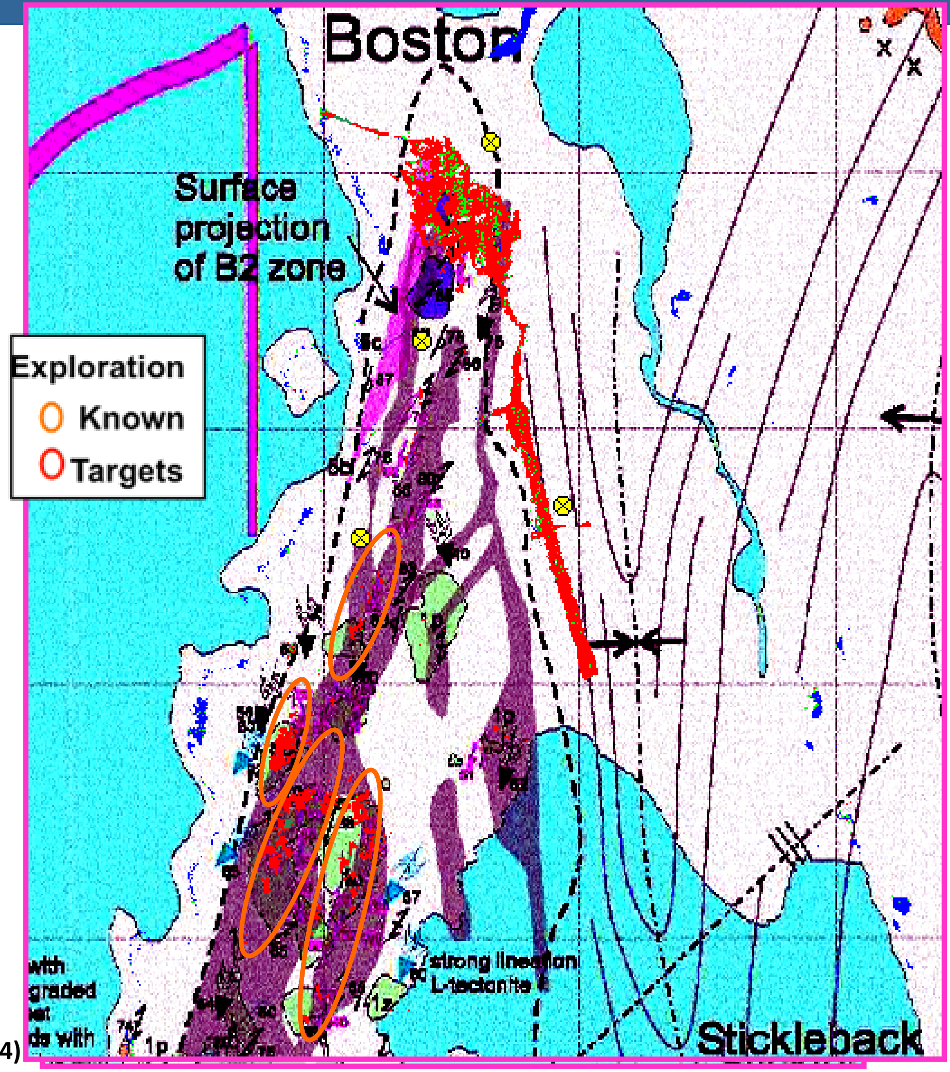
1	Mafic metavolcanic rocks, East Spider suite, non-variolitic: a, massive flows or subvolcanic intrusions; d, flow/pillow breccia, hyaloclastite, sediment-lava interaction textures; p, pillowed flow; j, interflow sedimentary rocks; y, amygdaloidal, commonly weathered-out; h, hornfelsed
1	Mafic metavolcanic rocks, West Spider suite, non-variolitic: a, massive flows or subvolcanic intrusions; d, flow/pillow breccia, hyaloclastite, sediment-lava interaction textures; p, pillowed flow; j, interflow sedimentary rocks; y, amygdaloidal, commonly weathered-out; h, hornfelsed
1	Mafic metavolcanic rocks, Boston suite, non-variolitic: a, massive flows or subvolcanic intrusions; d, flow/pillow breccia, hyaloclastite, sediment-lava interaction textures; p, pillowed flow; j, interflow sedimentary rocks; y, amygdaloidal, commonly weathered-out; h, hornfelsed
1	Mafic metavolcanic rocks, Boston suite, variolitic marker
	Strong alteration, Fe-carbonate, quartz, sericite and paragonite

Legend:
SINED mineral Potential results

- Illite - Low Al
- Illite Medium Al
- Illite High Al
- Pyrophyllite
- Chlorite

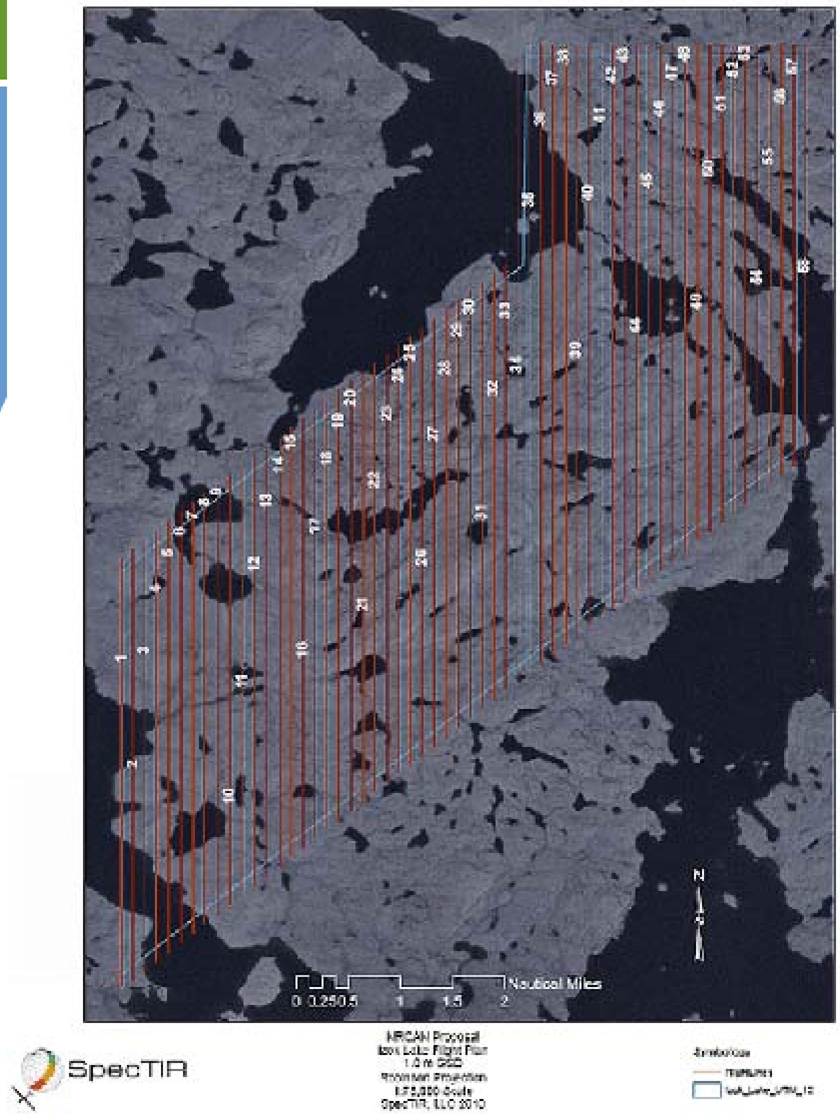
⊗ NUMIN (GSC) Au occurrences

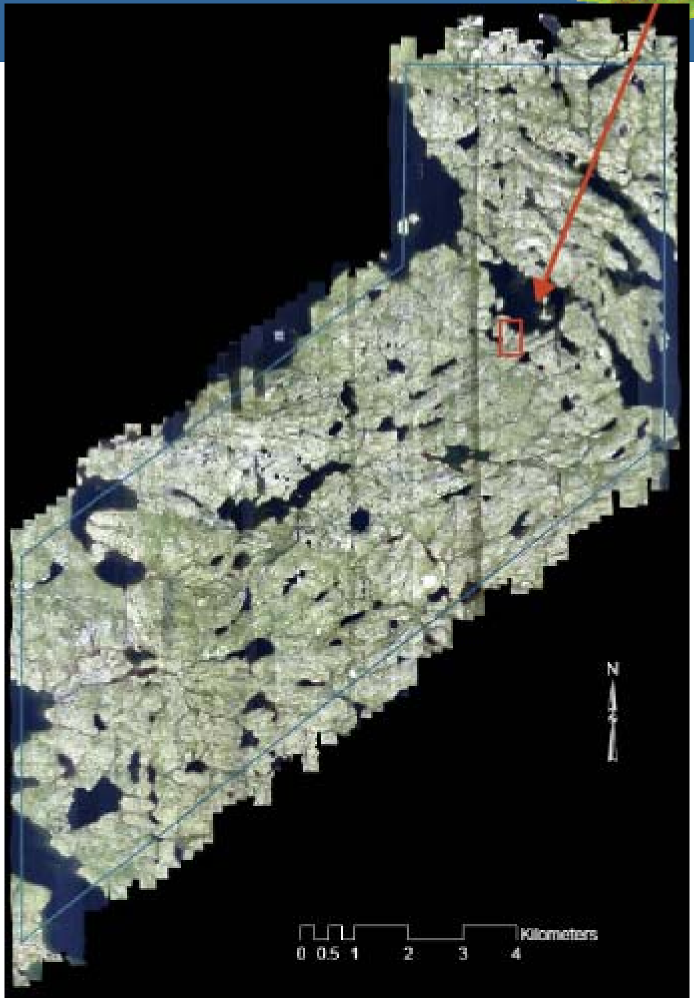
- High Al Illites here represent known exploration targets
- Other mapped pixels of high Al illite with common lithology relationships would be potential targets



IZOK LAKE - VMS

Izok Lake Survey

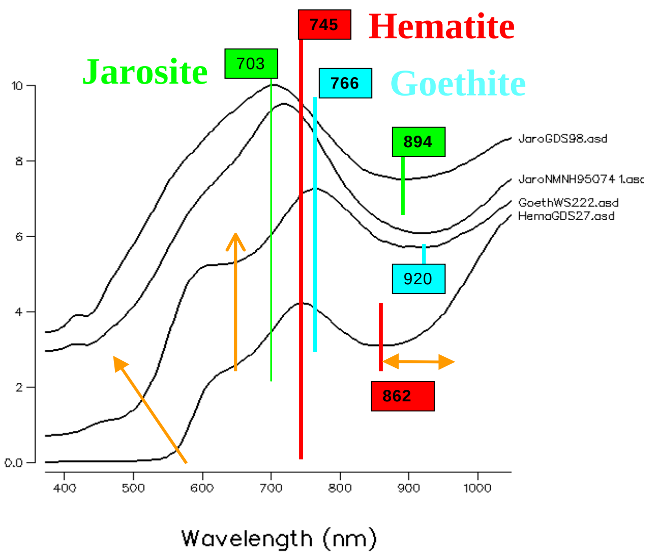




Airborne natural colour mosaic

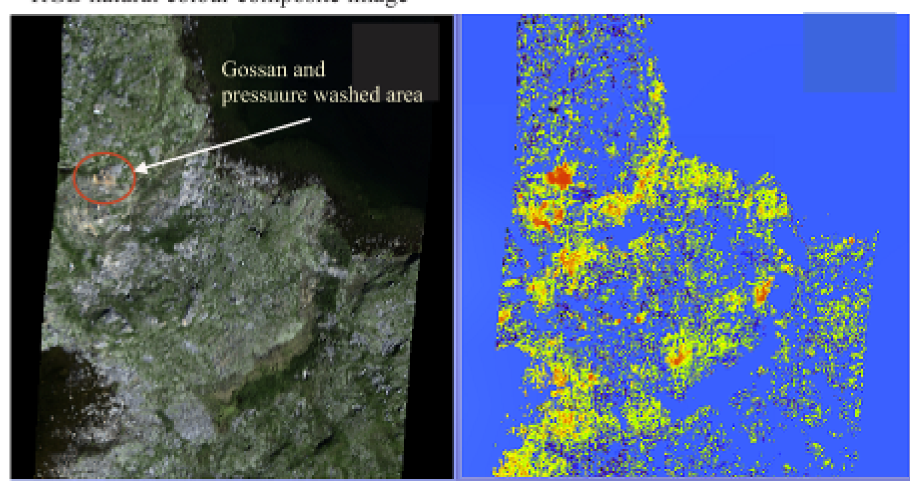
Izok Lake Survey - Gossans

- Analysis of the IZOK Lake data is only in the preliminary stages. However, the very high spatial resolution (1 meter) and high spectral resolution allows very small areas of gossan to be mapped. Further analysis is required with respect to other alteration minerals.



RGB natural colour composite image

Spectral Angle Mapper (SAM) Image using gossan spectra derived from the hyperspectral data



OK …we can't ignore the problems!!!

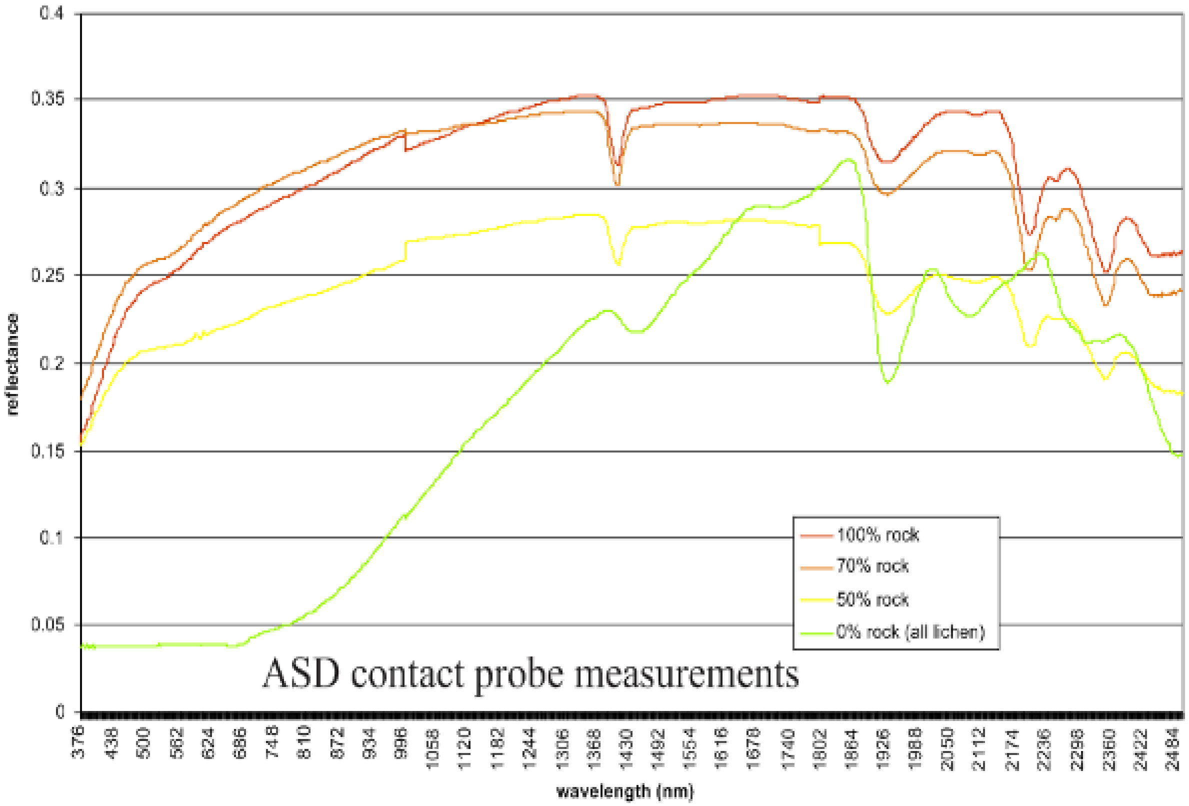
-Vegetation

- Lichen

-Weathering

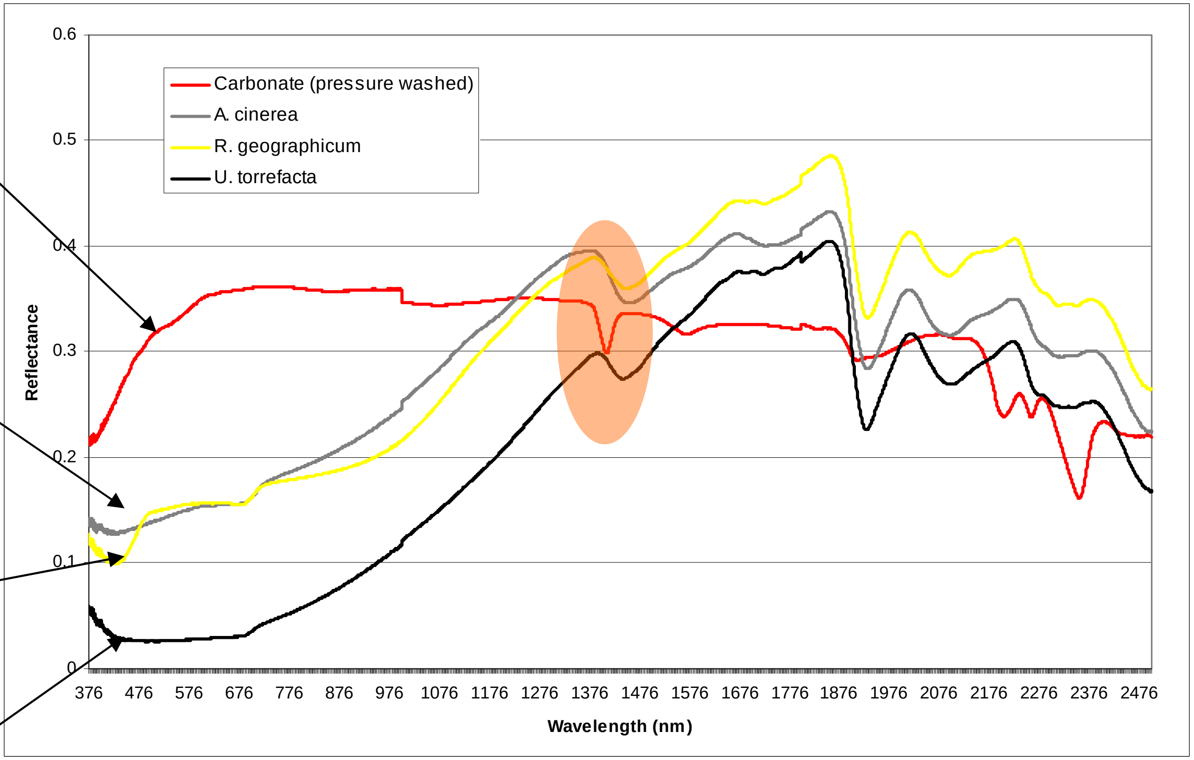
-Airborne / Satellite vs. Ground / Lab spectra

LICHEN! – cover density



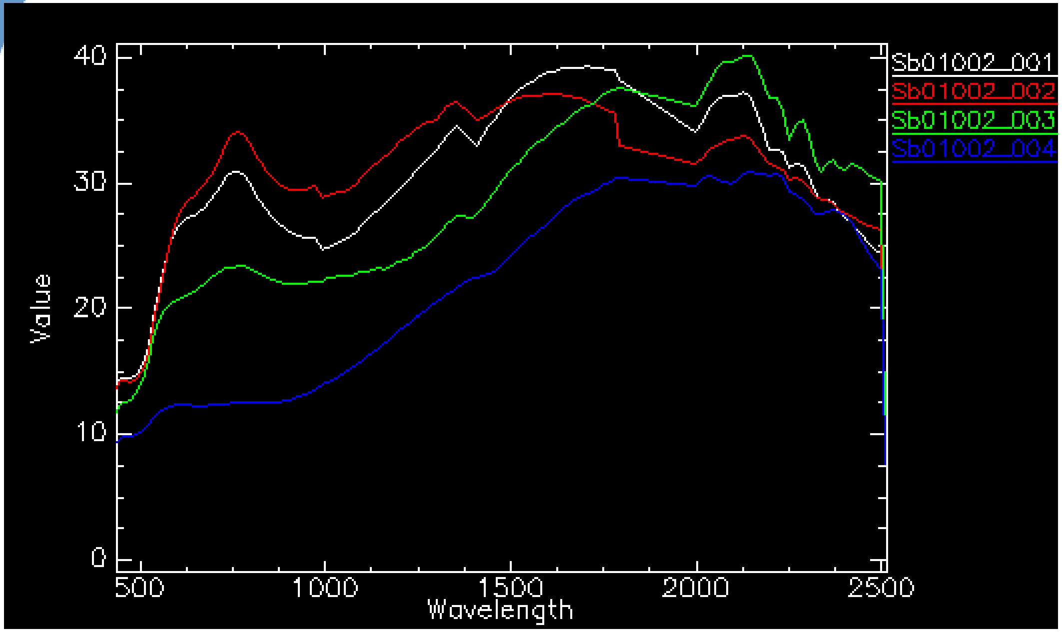
At 30% lichen cover (70% carbonate rock spectra) a strong carbonate spectrum is still evident. Even at 50% the carbonate spectrum can be seen (well sort of!) but when 100% lichen occurs the spectra is no longer discernable.

LICHEN – different species



spectra of rock encrusting lichens

Internal ASD spectra - psammites



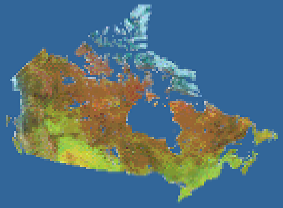
1 (white) = fresh < 20% garnet
2 (red) = fresh > 20% garnet
3 (green) = weathered (rust)
4 (blue) = weathered – 50% lichen

- Weathering lowers reflectance
- Lichen suppresses spectral features and imparts a typical vegetation signature on rocks
- Fe – reflection in .7 (red) (ferric) and absorption at ~ 1.0 (ferrous)

Summary - Mapping

- Hyperspectral data does contain lithologic information that can be used to produce a first pass spectral (lithologic) map to guide (and focus) field mapping activities
- Amount of exposure is key! - vegetation and lichen obscure important spectral features – how much lichen does it take to completely obscure???- we are still investigating this!
- For Canada’s North – great potential (and success) in Arctic Islands and areas near the coast – inland areas ---- yikes!!!
- Hyperspectral satellites are coming!
- Thermal infrared for silicates!!!

Summary (con't)



- This is airborne data and is **expensive!…**more appropriate at this time for specific mineralization/ alteration studies as opposed to regional mapping….until we have hyperspectral satellites similar to LANDSAT….we have **Hyperion** but only 7 km swath
- Hyperspectral data requires fairly **complex processing**
  - (atmospheric effects – more difficult in the North due to low sun angles
  - effects of topography on spectra
- What **spatial resolution** is really needed?…research issue
- What **spectral resolution** is really needed?….another research issue
- What are the **best methods to identify end- members** in areas of mixed rocks?
  - Traditional → linear unmixing, matched filtering etc?
  - Non-linear unmixing
  - Derivative analysis
- Spectral libraries for the Canadian environment are required!

Thank You

….Questions?